Robtic Refueling Mission (RRM)

Statement of Work for the Miniaturized Borescope Camera

Goddard Space Flight Center

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1 Introduction

1.1 Background

The Satellite Servicing Capabilities Office (SSCO) was established in 2009 to continue NASA's 40-year legacy of satellite servicing and repair. Among its various pursuits, SSCO has conducted a detailed engineering study of a notional mission: a free flying satellite with advanced robotics to perform refueling and other servicing. Restore is the internal name for this satellite servicing design reference mission.

In an effort to advance the various technologies that would be required to fly this notional Restore mission, SSCO has conducted several Demonstration of Technology Objectives (DTOs) both on the ground and on-orbit. The Robotic Refueling Mission (RRM) is one of these DTOs that was flown to the International Space Station (ISS) on-board the Space Transportation System (STS) 135 mission in July 2011. The primary goal of the RRM test bed is to advance robotic servicing technology by demonstrating the use of innovative robotic tools and techniques to remotely manipulate standard satellite interfaces that were not designed to be manipulated robotically.

RRM Phase 1 was successfully completed in early 2014. Phase 1 successfully demonstrated a variety of tasks, most notably the on-orbit transfer of fluid across a fill / drain valve interface. The success of RRM Phase 1 lead to a series of additional hardware being developed by SSCO as part of RRM Phase 2. This hardware was launched to the ISS aboard the Japan Aerospace Exploration Agency's (JAXA) HTV-4 in August 2013 and the European Space Agency's (ESA) Automated Transfer Vehicle (ATV-5) in July 2014. RRM Phase 2 included several pieces of hardware including the Visual Inspection Poseable Invertebrate Robot (VIPIR) vision system.

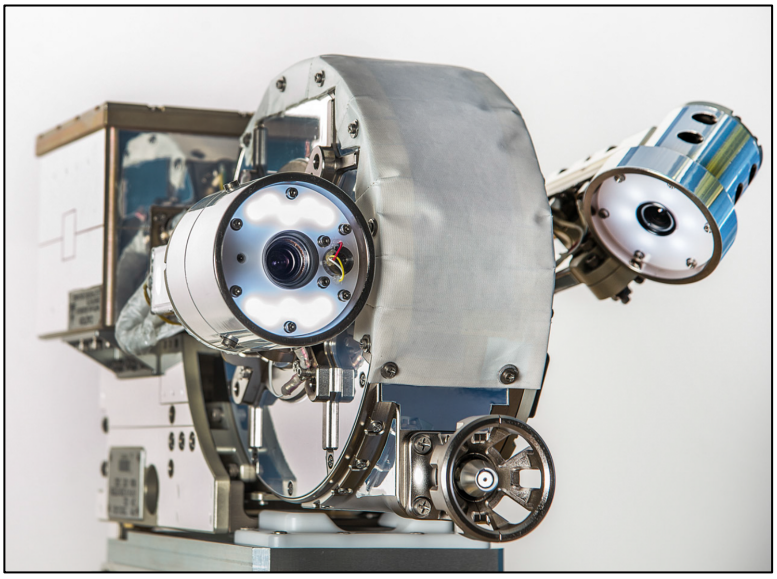

Figure 1: VIPIR Vision System with miniaturized borescope camera (bottom center)

VIPIR consists of an extendable and retractable borescope with an articulating tip. Inside of this tip is a miniaturized, 1.2mm diameter camera. The camera is packaged inside of a mechanical housing that includes six Light Emitting Diodes (LEDs) that provide illumination to the camera. VIPIR was conceived as a close quarters inspection tool capable of accessing hard to reach areas of satellites. VIPIR will be used to simulate inspection at locations that have proven to be hard to obtain imagery of, such as behind a sheet of thermal blanketing material, into a satellite's plumbing, or perhaps even deep inside the crevasses of a spacecraft bus. The VIPIR tool along with the rest of the RRM Phase 2 hardware is currently onboard the ISS awaiting operations which are expected in April, 2015.

1.2 Current Effort

SSCO is currently in the planning stages of RRM3. This effort will serve to demonstrate the capability to transfer Xenon gas and liquid Methane in zero-g using on-orbit, robotically mated transfer interfaces, while at the same time developing technologies that facilitate these capabilities. As part of RRM3, SSCO is planning to develop a second generation of the VIPIR tool. This tool is envisioned as having upgraded high resolution camera systems, more powerful optics, and updated LED lighting to provide a significantly more capable vision and inspection system from the previous generation. As such, SSCO is interested in upgrading the capabilities of the miniaturized borescope camera that resides at the end of the articulating tip of the Phase 2 VIPIR tool.

This document defines the work to be performed for Contractor design, development, fabrication, and delivery of the RRM3 miniaturized borescope camera, herein referred to as the Miniaturized Camera. In addition, this document spells out the hardware requirements of the Miniaturized Camera.

1.3 General Hardware Requirements

NASA SSCO desires the final, delivered product to be a fully integrated camera head unit. This camera head unit would contain the aforementioned Miniaturized Camera, integrated LED lighting, LED diffuser and a mechanical housing to contain all of the camera head components.

NASA SSCO acknowledges that this hardware build will contain commercial parts. As such, typical spaceflight environmental requirements are not included in this document. NASA will evaluate the final delivered product for its worthiness for spaceflight.

NASA SSCO also acknowledges that it is open to technical trades in regards to some of the requirements listed below. Therefore, it is requested that the Contractor note any specific requirement that it cannot meet and in response, provide an alternate technical approach that they believe is achievable. The Government will review all approaches.

Table 1-1 details the individual requirements for the Miniaturized Camera while Table 1-2 captures additional requirements for the fully integrated camera head unit.

Table 1-1: Miniaturized Camera Requirements

#	Specification	Details	Value
1	Detector	Image Sensor Type	CMOS
2	Detector	Wavelength Sensitivity	Visible ~400 to ~750 nm
3	Detector	Color Filter Array (CFA)	Bayer
4	Detector	Minimum pixel resolution	1000 x 1000
5	Detector	Minimum frame rate at 1000 x 1000 pixel image resolution	10 fps
6	Optical	Camera Field of View (FOV)	~100°
7	Optical	Maximum Near Depth of Field (DOF) limit	~ 5 mm
8	Optical	Minimum Far Depth of Field (DOF) limit	~50 mm
9	Electrical	Camera output format	Digital
10	Electrical	Camera video physical layer	LVDS
11	Electrical	Camera input voltage	3.3 V ± 10%
12	Electrical	Camera wire minimum diameter	0.008” (32 AWG)

Table 1-2: Integrated Camera Head Requirements

#	Specification	Details	Value
13	Mechanical	Maximum Outer Diameter (OD) of camera head	8 mm
14	Mechanical	Maximum length of camera head	8 mm
15	Mechanical	Camera head mechanical housing material	Aluminum
16	Mechanical	Camera head alignment feature	Required*
17	Electrical	Maximum integrated camera head input current	0.75 Amps
18	Electrical	Maximum camera head cable harness length	3 m
19	Electrical	Maximum OD of camera head harness bundle	3.5 mm
20	Electrical	Integrated LED lighting	Required**
21	Electrical	LED wire minimum diameter	0.008” (32 AWG)

*A flat or key feature is required on the surface of the outer diameter of mechanical housing of the Integrated Camera Head unit. Its purpose is to define the relationship between the mechanical housing and the orientation of the Miniaturized Camera Head imagery.

**Specific number of individual LEDs and their arrangement in the final Integrated Camera Head unit is open to design trade to meet maximum camera head outer diameter (OD) requirement (Requirement #14).

1.4 Hardware Deliverables

The Contractor shall provide the facilities, personnel, services, tools, equipment, and materials necessary to deliver the Miniaturized Camera for the Integrated Camera Head unit for RRM3.

The Contractor shall fabricate, test and deliver the following units of hardware/software:

- Order quantity of five (5) prototype camera head units, as defined by the requirements listed in Tables 1-1 and 1-2. SSCO is keenly interested in getting early prototypes of the camera head units in house for both evaluation purposes as well as development of our own internal Video Processor Unit (VPU) that will interface to the camera heads.

- Order quantity of ten (10) camera head units of the final, all-inclusive design as defined by the requirements listed in Tables 1-1 and 1-2. These units will incorporate any hardware, firmware, or software changes agreed upon by both SSCO and the Contractor, resulting from the evaluation of the aforementioned prototype camera head units.

- Order quantity of one (1) Electrical Ground Support Equipment (EGSE) consisting of a Video Processor Unit (VPU) capable of reading, formatting, demosaicing, displaying, and saving the raw camera output coming from the final camera head units.* Additionally, the VPU EGSE should have the capability to independently turn on, off and dial the intensity of the camera head LEDs.

*Note: If the prototype camera head units require a different set of EGSE than the final versions, then an additional prototype-only set of EGSE is also required.

1.5 Other Deliverables

- The demosaicing algorithm that interpolates color imagery from the raw Bayer pattern video data from the camera shall be made available to SSCO in the following forms:
    - Pseudo-code: a top level description of the implementation of the demosaicing algorithm.
    - Algorithm Description Document (ADD): A document detailing the mathematics that power the demosaicing algorithm.

  SSCO does not require specific access to the Contractor's source code for the demosaicing algorithm, but will accept it in lieu of the items described above.

- An electrical Interface Control Document (ICD) detailing the electrical interface of the Integrated Camera Head. This document shall contain detailed specifications regarding the pin outs of the camera head connector, the format of the video physical layer, and the video protocol transmitted over that layer. Additionally, the format of any camera command blocks (if applicable), as well as any other pertinent information that GSFC will need to power, control and command the camera head is required. The Contractor must include in the ICD any detailed technical information regarding advanced capabilities of the Miniaturized Camera sensor such as automatic gain control (AGC), windowing, tiling, etc.

- The Contractor shall provide 10 hours of post-delivery technical support via phone and/or email regarding the Miniaturized Camera.

2 Management, Reporting, Documentation and Reviews

2.1 Management and Reporting

The Contractor shall designate a single individual who will be given full responsibility and authority to manage and administer all phases of the work specified by the contract, and ensure that all objectives are accomplished within schedule and cost constraints.

The Contractor shall provide for managing all resources, controlling schedules, managing all engineering, manufacturing and procurement activities, configuration management, Quality Assurance, documentation control, and distribution.

The Contractor shall prepare and present to the NASA/GSFC Technical Representative monthly status via telecon and a written report. The report shall be a summary presentation of the period's progress, problem areas, and activities on-going and planned. The Contractor shall generate a list of significant milestones that will enable NASA/GSFC to ascertain program progress. The designated Contractor point of contact to GSFC will be responsible for scheduling the monthly status telecons with the NASA/GSFC Technical Representative.

2.2 Reviews and Meetings

NASA SSCO requires the following meetings to take place as part of this contract:

2.2.1 Kick-Off Meeting (KO)

The Contractor shall organize and present a Kick-Off Meeting to a NASA/SSCO Review Team at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Maryland within three (3) months After Receipt of Order (ARO). This meeting may be conducted using video conferencing capabilities, if the Contractor prefers this method of correspondence. This meeting shall demonstrate overall conformance of the proposed hardware design to the requirements specified in this document. The Contractor shall provide details of proposed prototypes including its comparison in form, fit and function to the final camera head units. This meeting shall cover programmatic, technical, schedule, test and verification, and quality assurance topics. Demonstration of any currently available hardware is encouraged.

The Contractor shall provide to SSCO the Kick-Off presentation package and all other required deliverable data in electronic format within one week of the formal Kick-Off meeting.

The Contractor shall prepare the review minutes. The review minutes shall include, at a minimum, the attendance, action items, and action item responsibility.

2.2.2 Critical Design Review (CDR)

The Contractor shall organize and conduct a Critical Design Review at either the Contractor's facility or at NASA's Goddard Space Flight Center in Greenbelt, MD before the fabrication program begins for the final deliverable camera head units. This meeting may be conducted using video conferencing capabilities, if the Contractor prefers this method of correspondence. This review shall demonstrate overall conformance of the proposed hardware design to the requirements specified in this document. The Contractor shall highlight any changes in the final design from that of the prototype camera head units. SSCO requests that the Contractor provide an as-designed parts list for the prototype camera head unit prior to the CDR.

The Contractor shall provide to SSCO the CDR presentation package and all other required deliverable data in electronic format within one week of the CDR meeting.

The Contractor shall be prepare the review minutes. The review minutes shall include , at a minimum, the attendance, action items, and action item responsibility.

3 Engineering

3.1 General Requirements

The Contractor shall perform analyses of the technical requirements specified in this document to ensure compliance of the hardware fabrication and to assemble the documentation necessary to ensure its usability by NASA/SSCO users.

3.2 Engineering Documentation

The following documents are required to be submitted by the Contractor as part of this contract.

3.2.1 Mechanical Hardware Documentation

- High Fidelity mechanical CAD model for the integrated camera head unit.
- A top-level mechanical Interface Control Document (ICD) that details the mechanical properties of the as-built integrated camera head units.
- Mechanical assembly drawings showing how the integrated camera head unit is assembled from subassembly and component parts.

3.2.2 Electrical Hardware Documentation

- As-designed parts lists for the prototype camera head unit. The list shall include the original equipment manufacturer (OEM) of each part, its corresponding OEM part number, serial number, lot number or any other relevant traceability information.
- As-built parts lists for the integrated camera head unit. The list shall include the original equipment manufacturer (OEM) of each part, its corresponding OEM part number, serial number, lot number or any other relevant traceability information.
- An electrical Interface Control Document (ICD) detailing the electrical interface of the Integrated Camera Head. This document shall contain detailed specifications regarding the pin outs of the camera head connector, the format of the video physical layer, and the video protocol transmitted over that layer. Additionally, the format of any camera command blocks (if applicable), as well as any other pertinent information that GSFC will need to power, control and command the camera head is required. The Contractor must include in the ICD any detailed technical information regarding advanced capabilities of the Miniaturized Camera sensor such as automatic gain control (AGC), windowing, tiling, etc (as previously mentioned).
- Documentation regarding the camera's demosaicing algorithm (as previously mentioned).
- The OEM manufacturer's specification document for the Focal Plane Array (FPA) used in the integrated camera head unit.

3.2.3 Data Delivery Package

The final Data Delivery Package shall be made available to ship with the final batch of delivered integrated camera head units. The package should be comprised of, but not limited to, the following data:

- As-Built vs. As Designed Parts List, (includes serialization/revisions)
- Materials and Processes List
- Final Drawing Package (including rework instructions, if any)
- Problem/anomaly reporting (complete copies of report)
- Deviations/Waivers/open items/nonconformances and their dispositions
- Log of total operating time
- Certificate of Conformance
- Open Items with proposed closure dates
- As-run test procedures and results for all functional performance tests
- As-run test procedures and results for all electrical tests
- Final versions of the mechanical and electrical ICDs
- Final versions of the mechanical CAD model
- Final mechanical assembly drawings
- Final version of the Algorithm Design Document, or other documentation relevant to the demosaicing algorithm
- Focal Plane Array (FPA) specification documentation

Minor deviations in the Data Delivery Package may be reviewed and approved on a case-by-case basis by the NASA/SSCO Technical Representative.

The Contractor shall provide to SSCO the Data Delivery Package in electronic format upon delivery of final hardware. Specific elements of the Data Delivery Package may be required for individual delivery prior to delivery of final hardware. These elements have been highlighted in the Schedule section of this Statement of Work document. The Contractor has the option to provide NASA with draft copies of any individual data items listed in the data delivery package ***as early as possible***, in particular the mechanical and electrical ICDs.

4 Handling, Storage, Packaging, Preservation, and Delivery

Products shall be stored, preserved, marked, labeled, packaged, and packed to prevent loss of marking, deterioration, contamination, excessive condensation and moisture, or damage during all phases of the program.

Contractor is responsible for providing an acceptable shipping container that protects the hardware appropriately, such as a pelican case or similar container. While in a shipping container, the integrated camera head units shall be stored in an ESD-safe container.

The Contractor shall ship to NASA GSFC in Greenbelt, Maryland. The Contractor will be responsible for any damage incurred during shipment.

5 Schedule

The Contractor shall furnish and deliver the supplies/documentation and perform the services required by this Statement of Work in accordance with the schedule set forth below:

Item	On or Before	Shipping Class
Contractor shall conduct Monthly Status Meeting/Reports.	Beginning one (1) month ARO and continuing until delivery of all camera head units	Class IV*
Contractor holds official Kick-Off Meeting	Within three (3) months ARO	N/A
Contractor supplies NASA/GSFC with a Kick-Off Presentation Package and associated data.	Within one (1) week of Kick-Off Meeting ending	Class IV
Contractor holds official Critical Design Review.	Prior to Manufacturing of final hardware deliverables	N/A
Contractor supplies NASA/GSFC with a CDR Presentation Package and associated data.	Within one (1) week of CDR ending	Class IV
Contractor supplies NASA/GSFC with an electrical Interface Control Document.	No later than two (2) weeks prior to final hardware unit delivery . Early draft requested as soon as it is available.	Class IV
Contractor supplies NASA/GSFC with a Drawing Package.	No later than two (2) weeks prior to final hardware unit delivery . Early draft requested as soon as it is available.	Class IV
Contractor delivers quantity five (5) prototype integrated camera head units to NASA/SSCO.	No later than March 2016	Class III
Contractor delivers quantity one (1) EGSE Video Processor Unit (VPU) to NASA / SSCO.	To accompany prototype hardware delivery	Class III
Contractor delivers quantity ten (10) fully integrated camera head units to NASA/SSCO.	No later than September 2016	Class III
Contractor delivers quantity one (1) EGSE Video	To accompany final hardware delivery, if	Class III

Processor Unit (VPU) to NASA / SSCO, if applicable	applicable	
Contractor supplies NASA/GSFC with a final Data Delivery Package.	To accompany final hardware unit delivery	Class IV
Contractor provides 10 hours of post-delivery technical support via phone and email regarding the integrated camera head unit.	Post-delivery of hardware	N/A

***NOTE: All deliverables, other than reports/documentation, are designated as Shipping Class III. All reports/documentation deliverables specified under the Schedule, unless specified (electronic/format, etc.), are considered Class IV and shall be shipped via the most advantageous commercial transportation means considered to be in the best interest of the Government.**